AGN Reverberation Mapping with STOBE-X

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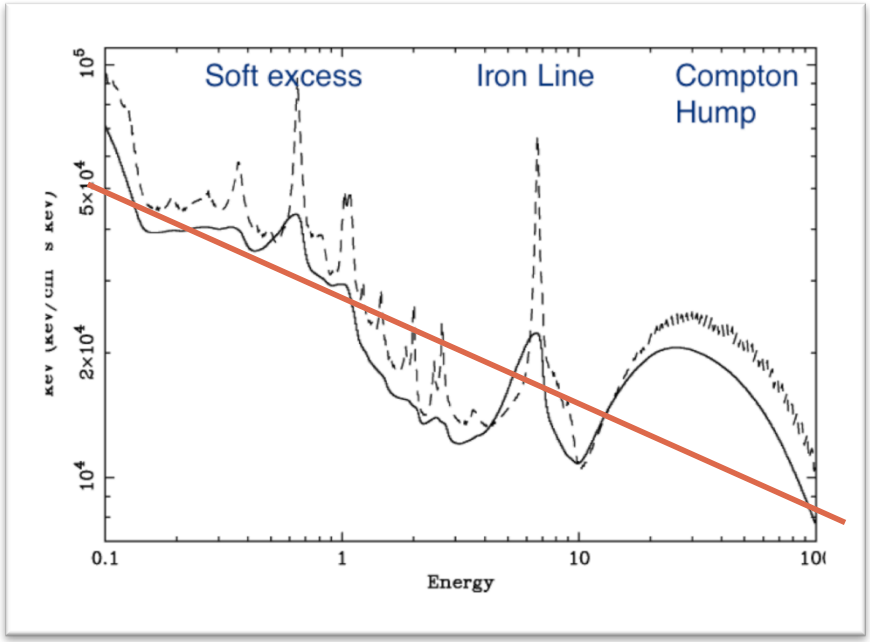
X-ray Reverberation

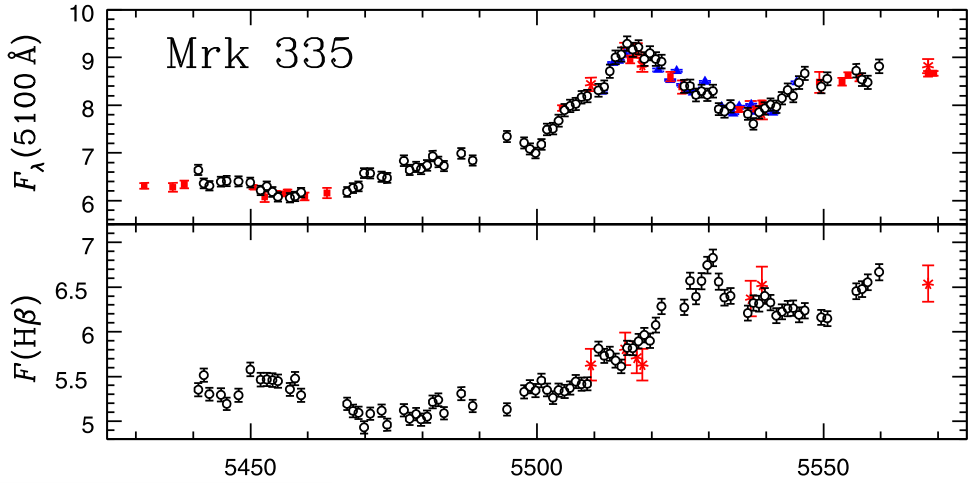
- X-ray emission originates **close** to the BH.
- Fast variability + Reflection: → Reverberation
- In AGN, the **reflection spectrum** reverberates.
- In BHB, the **blackbody** from the disk may reverberate (See Ed Cackett's talk).

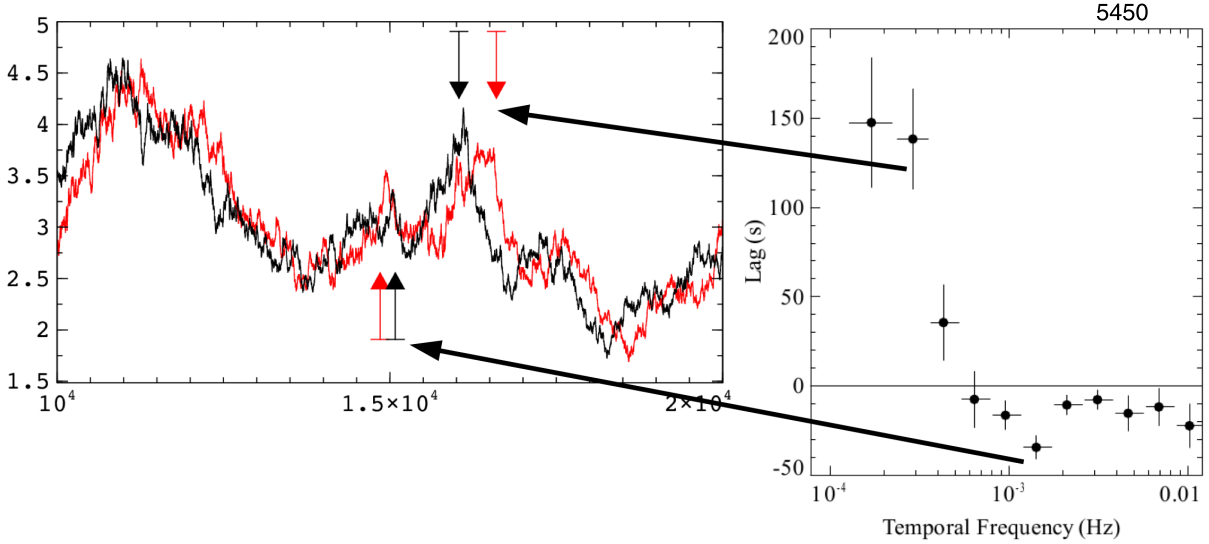


X-ray Reverberation

- Unlike optical reverberation, X-ray lags in AGN are **timescale-dependent** → Frequency-dependent

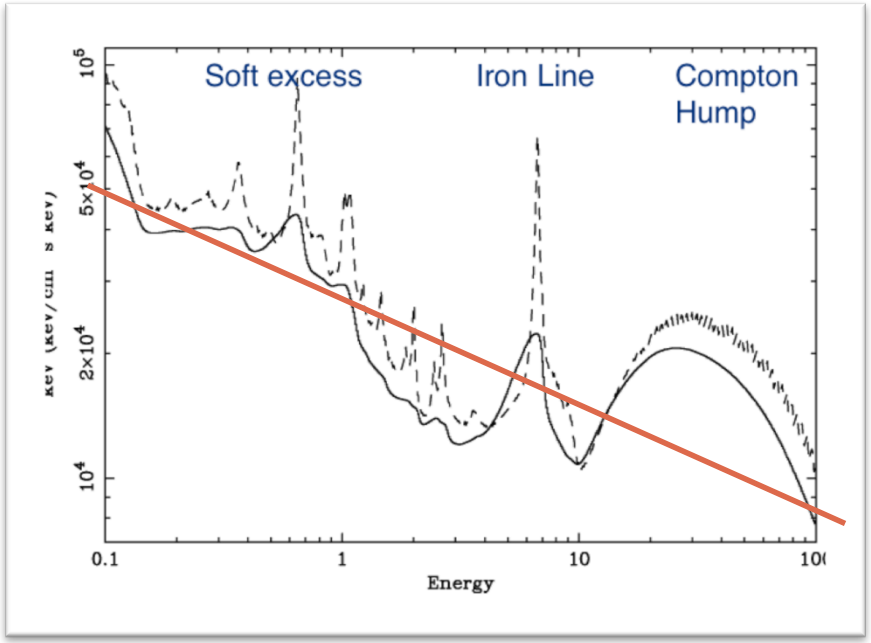
Grier+12





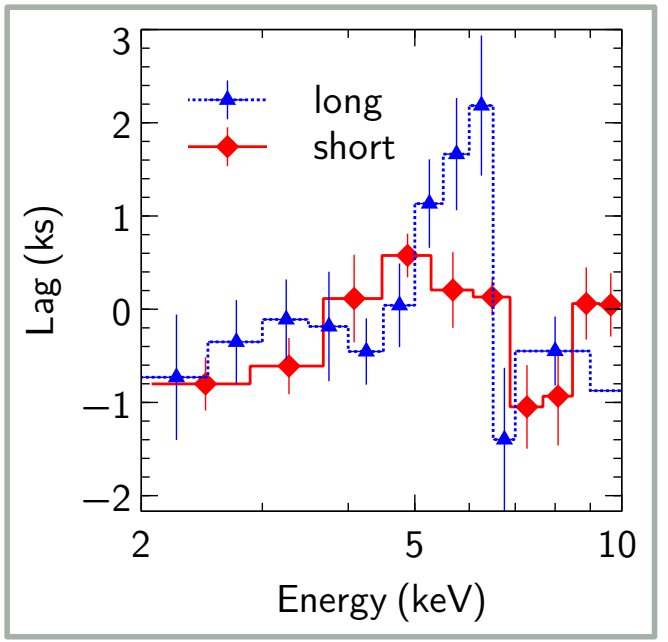
Observed Reflection Lags

- First seen in the **soft excess** (Fabian+09, AZ +10,11 etc.)



Observed Reflection Lags

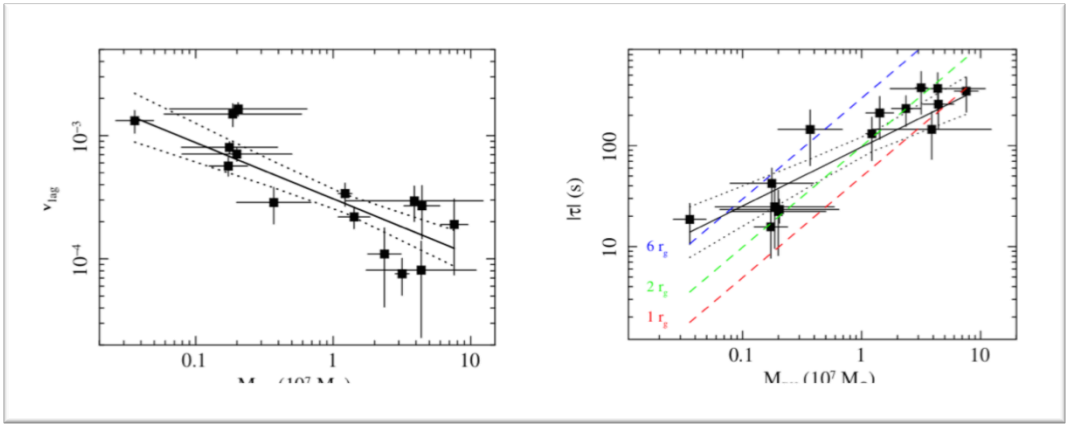
- First seen in the **soft excess** (Fabian+09, AZ +10,11 etc.).
- The **iron K Line** (AZ +12,13,15, Kara+13,14).



Lags Are Correlated With Mass

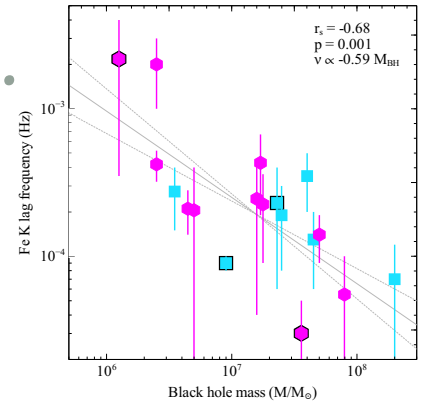
- Seen in the **soft excess**.

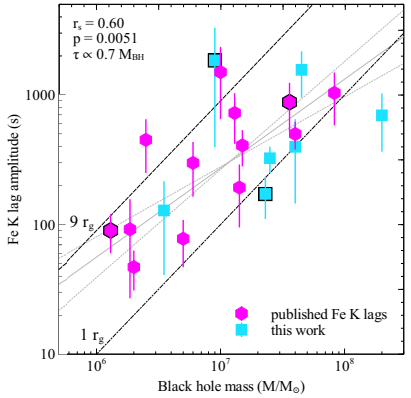
(De Marco+12)



- Then in the **iron K Line**.

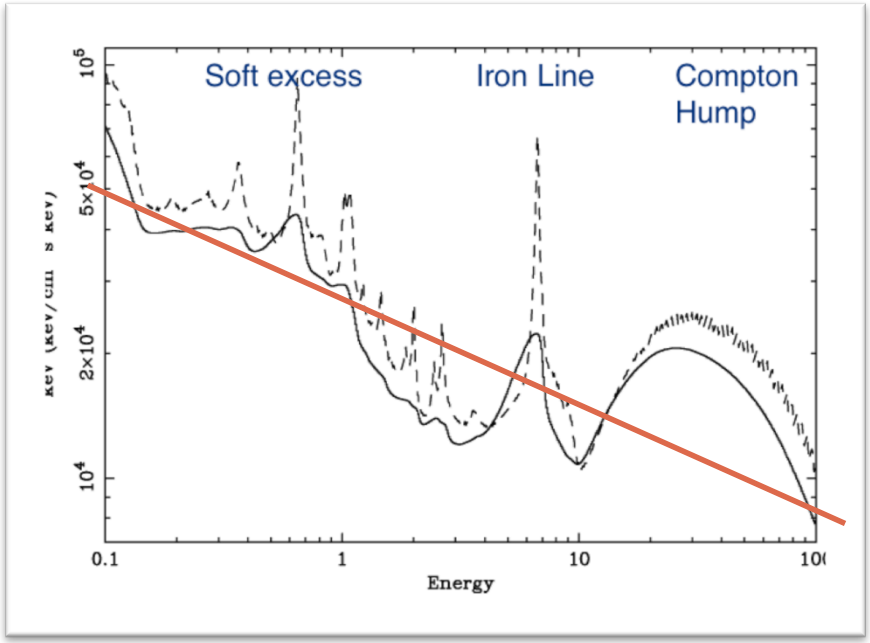
(Kara+16)





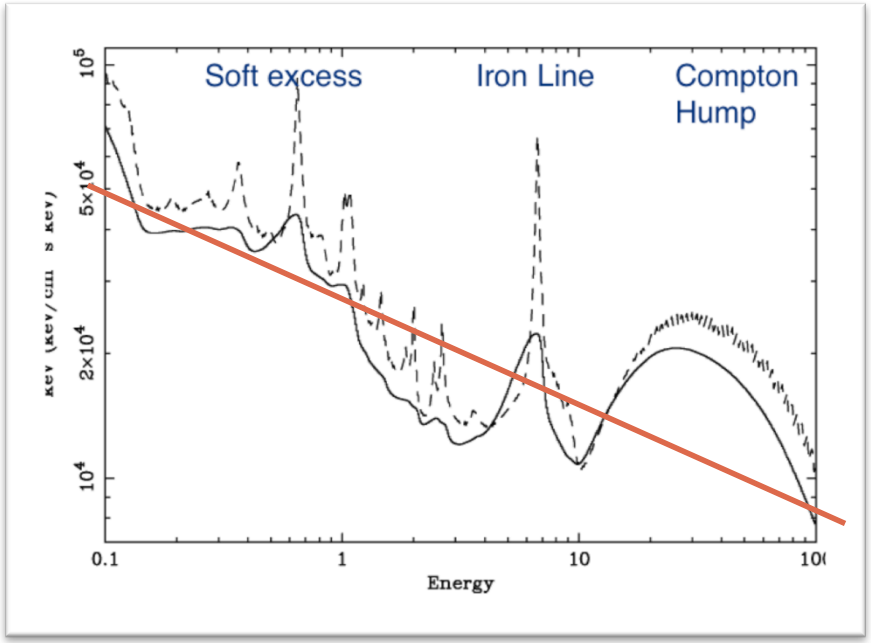
Observed Reflection Lags

- First seen in the **soft excess** (Fabian+09, AZ +10,11 etc.).
- The **iron K Line** (AZ +12,13, Kara+13,14).
- The **Compton Hump** possibly (AZ+15, Kara +15).



Observed Reflection Lags

- Lag vs frequency for two energy bands.
- Lag vs energy at some frequency → reflection fraction.
- Current modeling attempts



The Next Steps With STROBE-X: Sensitivity

- Signal considerations.

$$\Delta\phi(f) = N^{-1/2}\sqrt{\frac{2}{P_1 P_2 R_1 R_2} + \frac{1}{P_1 R_1} + \frac{1}{P_2 R_2}}$$

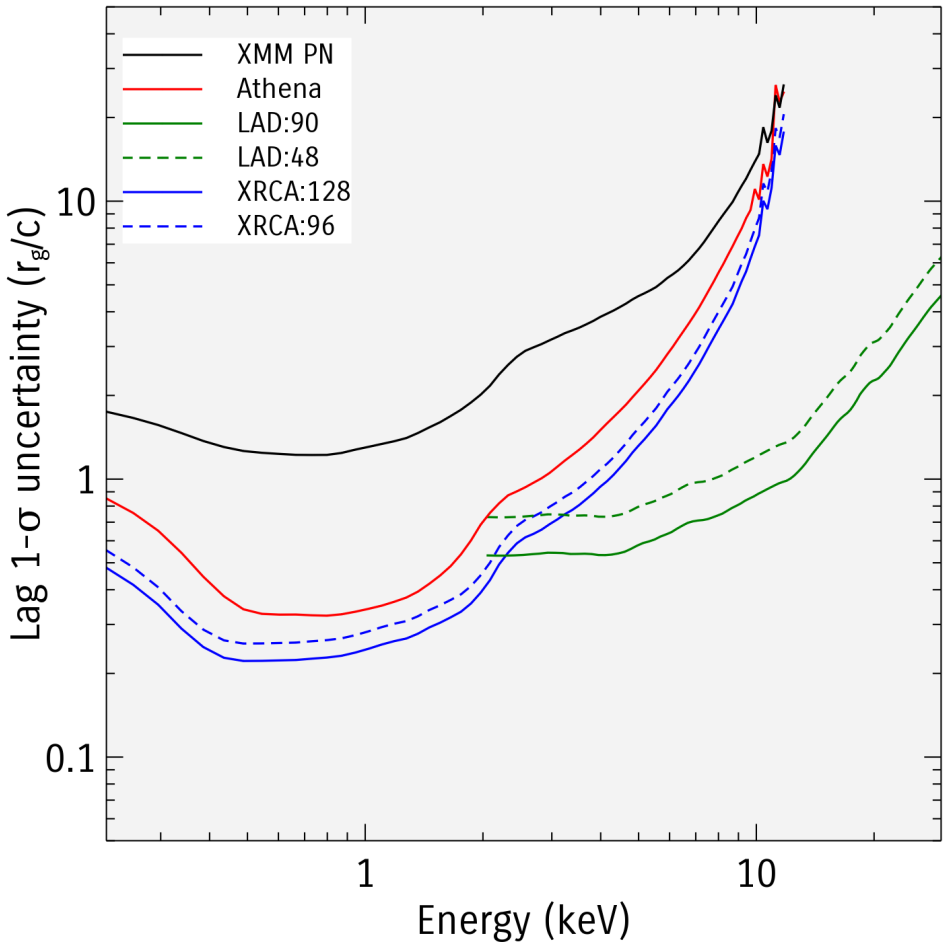
  - N: Num. of Frequencies: observation length & frequency band.
  - P: Intrinsic to the object.
  - R: 'Noise factor' related to detector sensitivity.

- Assume:

$$P \propto M_{\rm BH}$$
$$F_{2-10{\rm keV}} = 4 \times 10^{-11}\,{\rm erg\,cm^{-2}\,s^{-1}}$$
$$\text{responses} \rightarrow \mathrm{R}$$

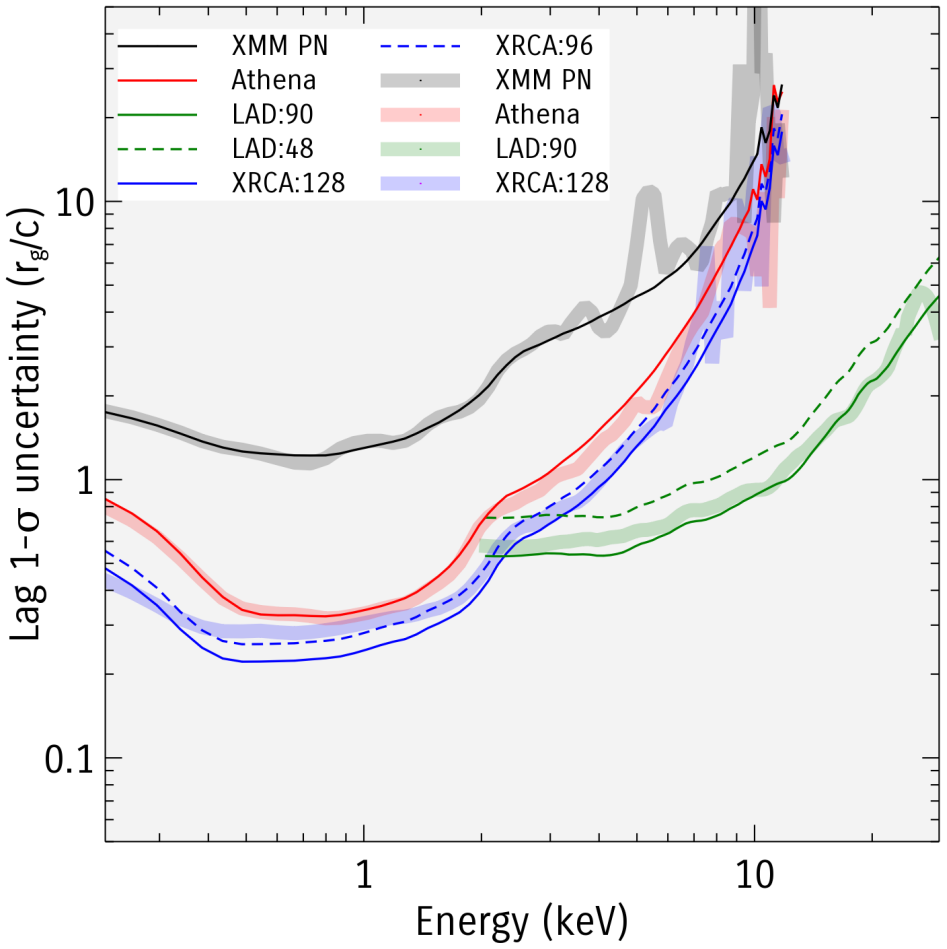
The Next Steps With STROBE-X: Sensitivity

- Lag sensitivity plot.



The Next Steps With STROBE-X: Sensitivity

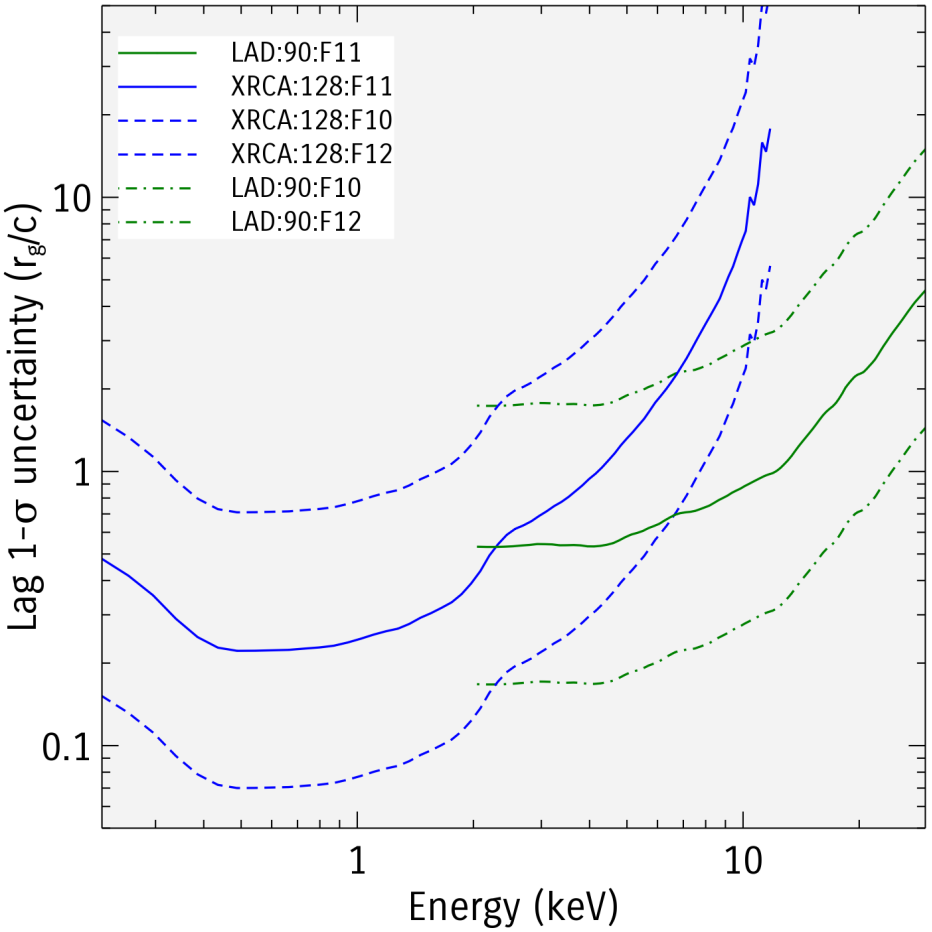
- Lag sensitivity plot.
- Curves match simulated light curves.



The Next Steps With STROBE-X: Sensitivity

- Lag sensitivity plot.
- Curves match simulated light curves.
- Using a range of fluxes:

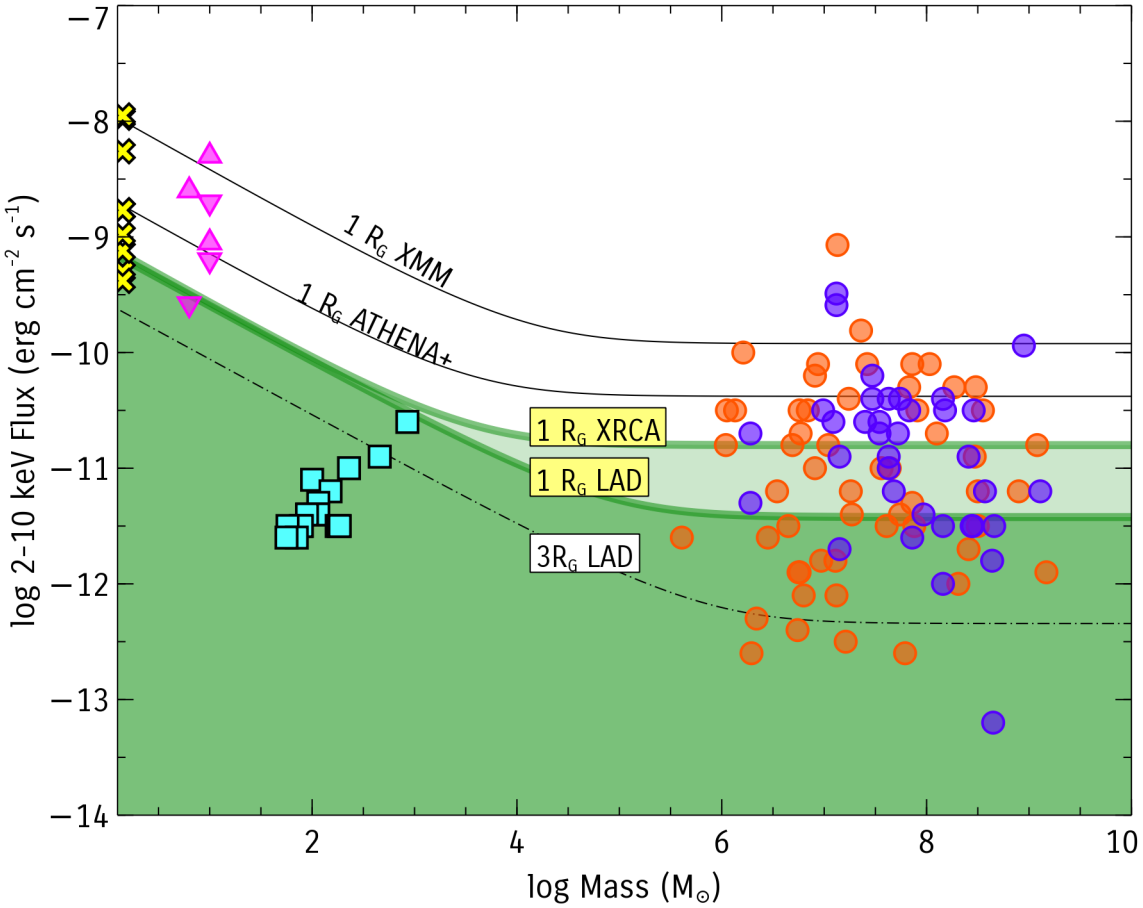
$$4 \times 10^{[-12,-11,-10]} \mathrm{erg\,cm^{-2}\,s^{-1}}$$



The Next Steps With STROBE-X: Sensitivity

- Sources to be explored: Using the Flux-Mass space.

- Blue: AGN with reverberation masses.
- Orange: AGN with mass from masses from Hβ widths.
- Cyan: ULX, assuming IMBH.
- Magenta: Stellar Mass BH.
- Yellow: NS



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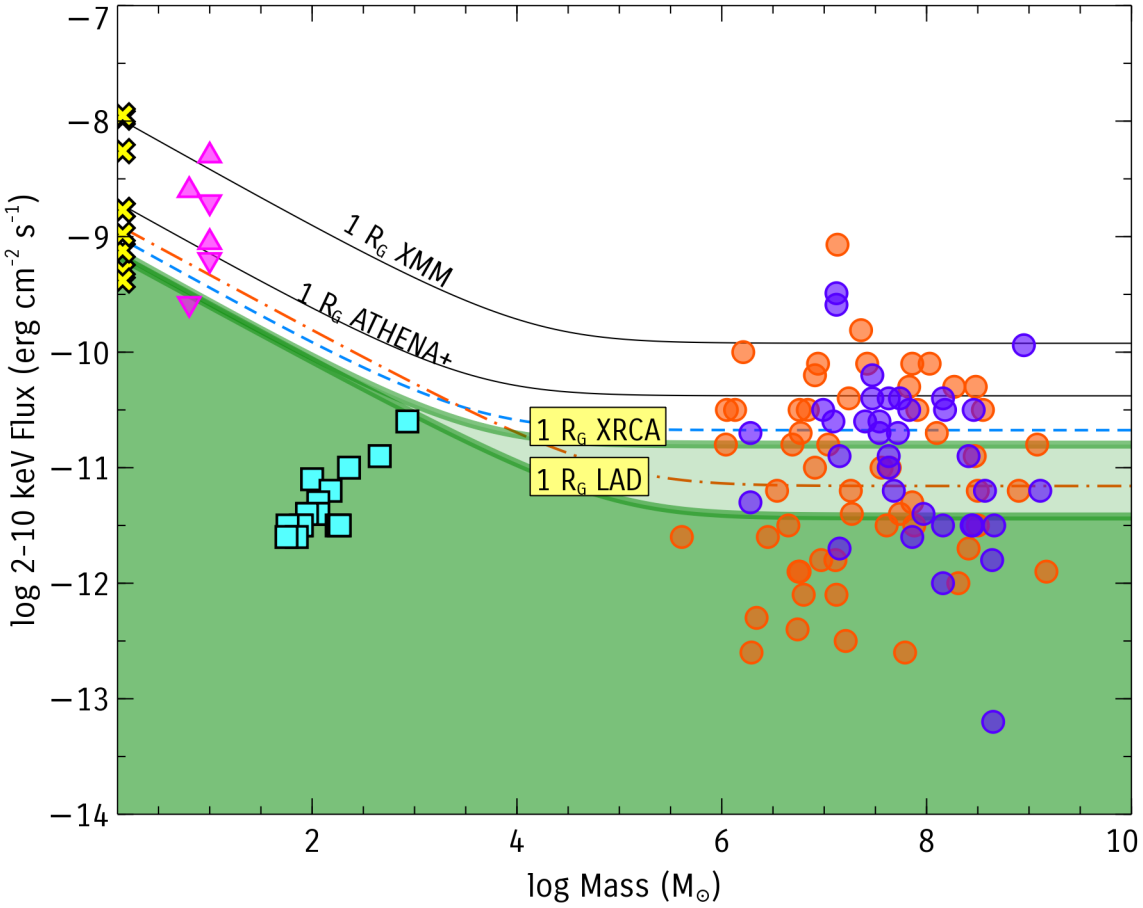
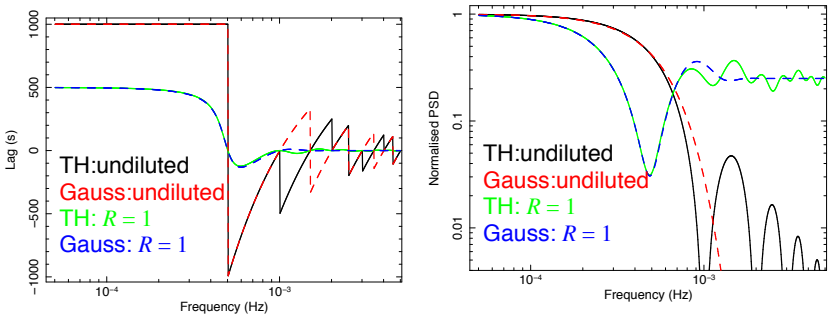
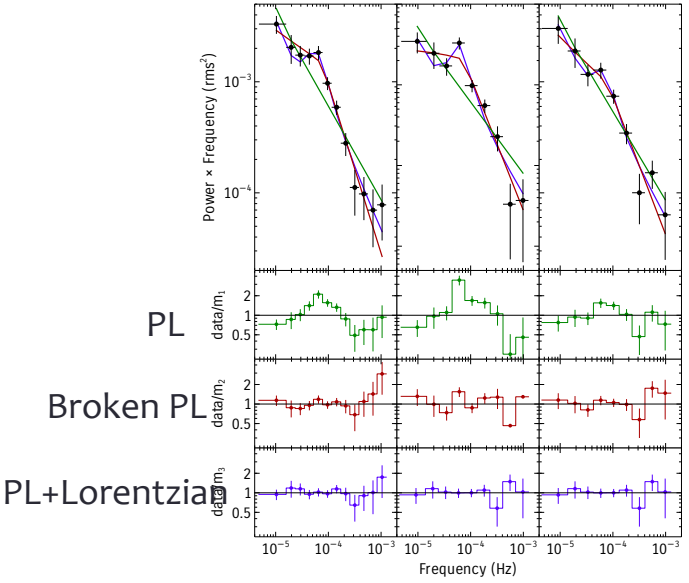


STROBE-X: The Measurements

- **What will we measure?**
  - Signature of Reverberation in PSD





STROBE-X: The Measurements

- **What will we measure?**
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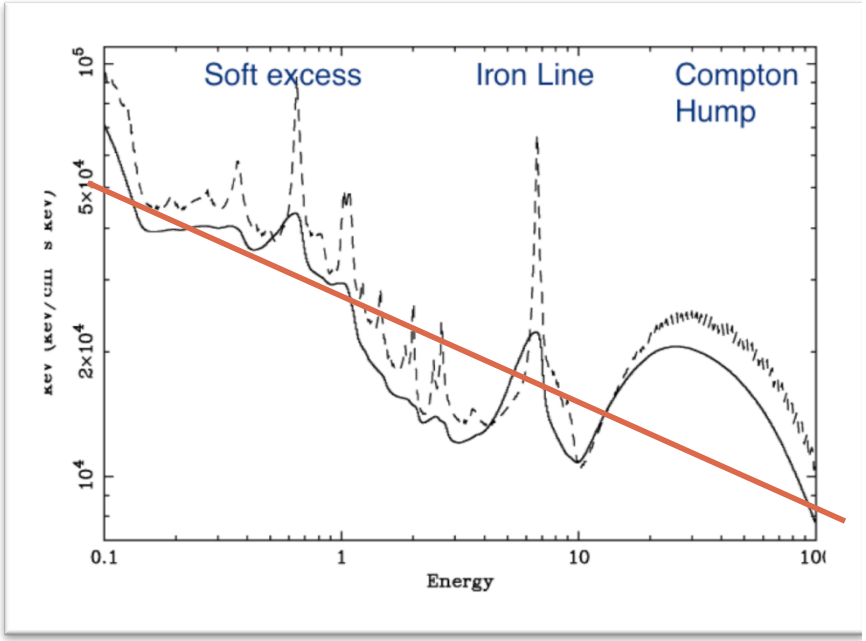
  - Detailed Lag-energy Spectra.



STROBE-X: The Measurements

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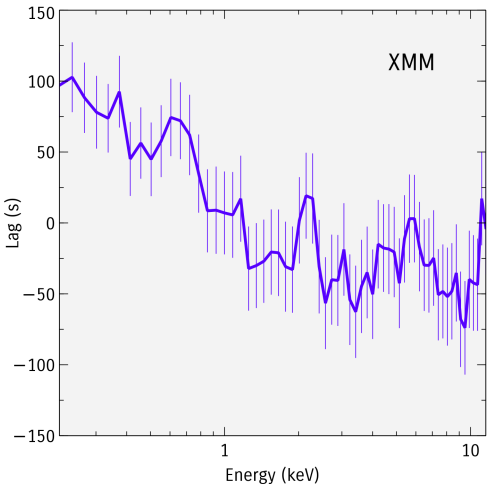

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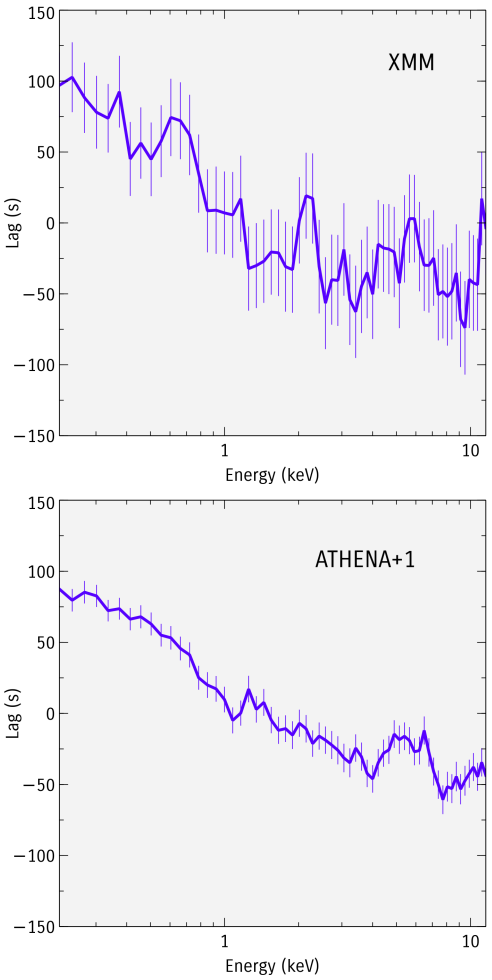

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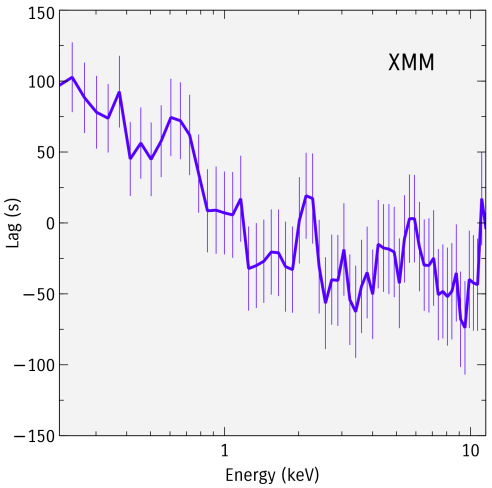

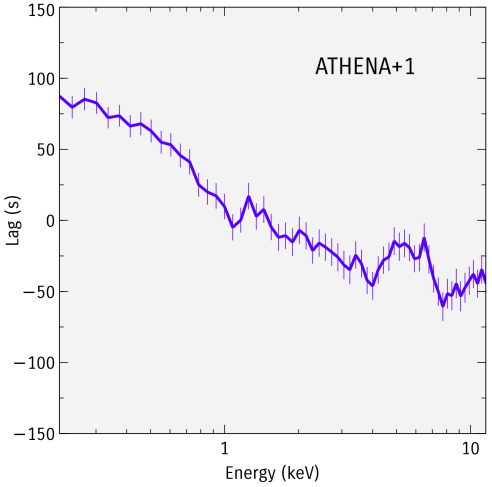

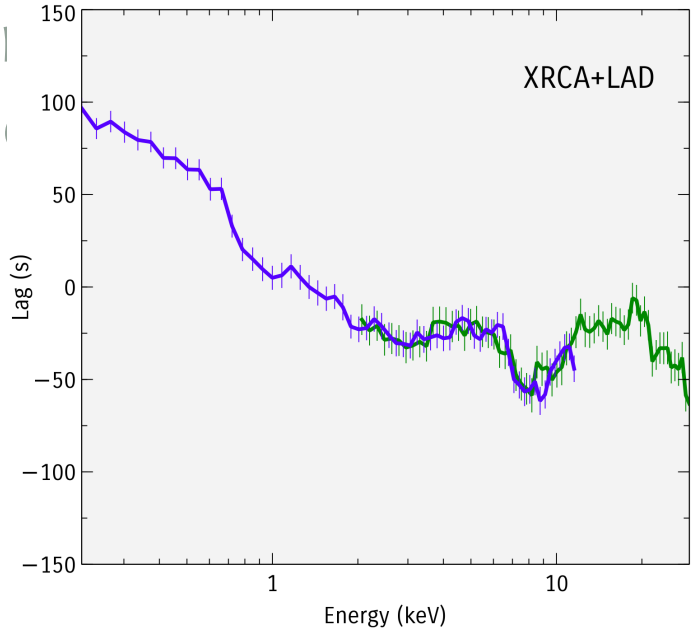

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- **What will we measure?**
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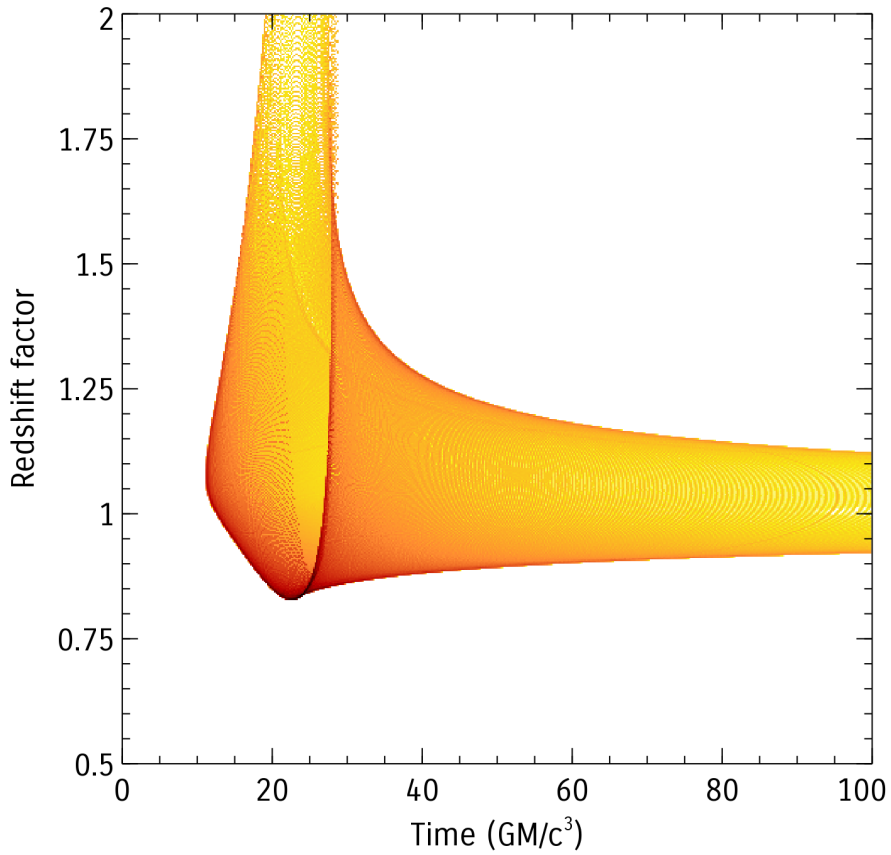
  - Detailed Lag-energy Spectra across the whole band.
  - Relativistic Response Function → Geometry (Wilkins+15,16).



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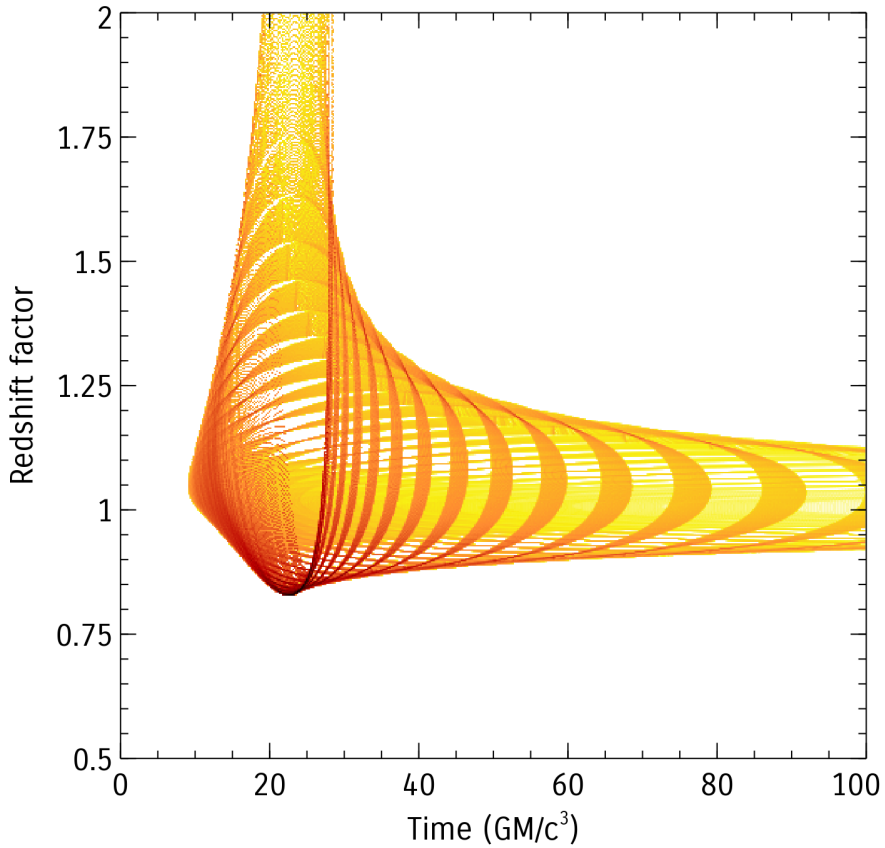

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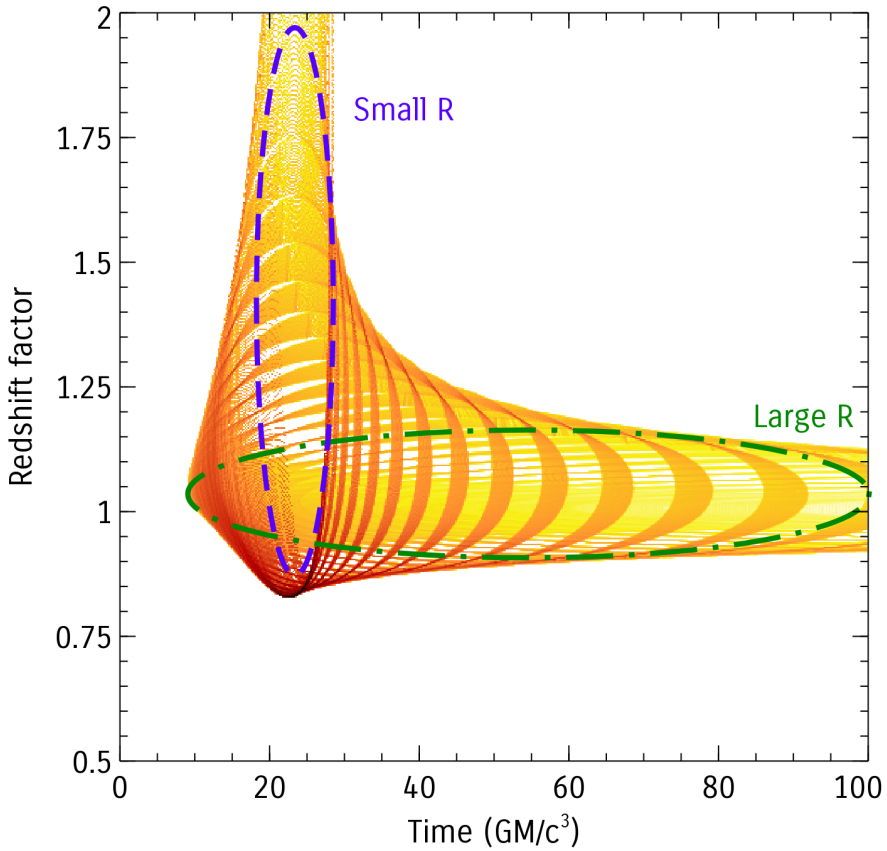

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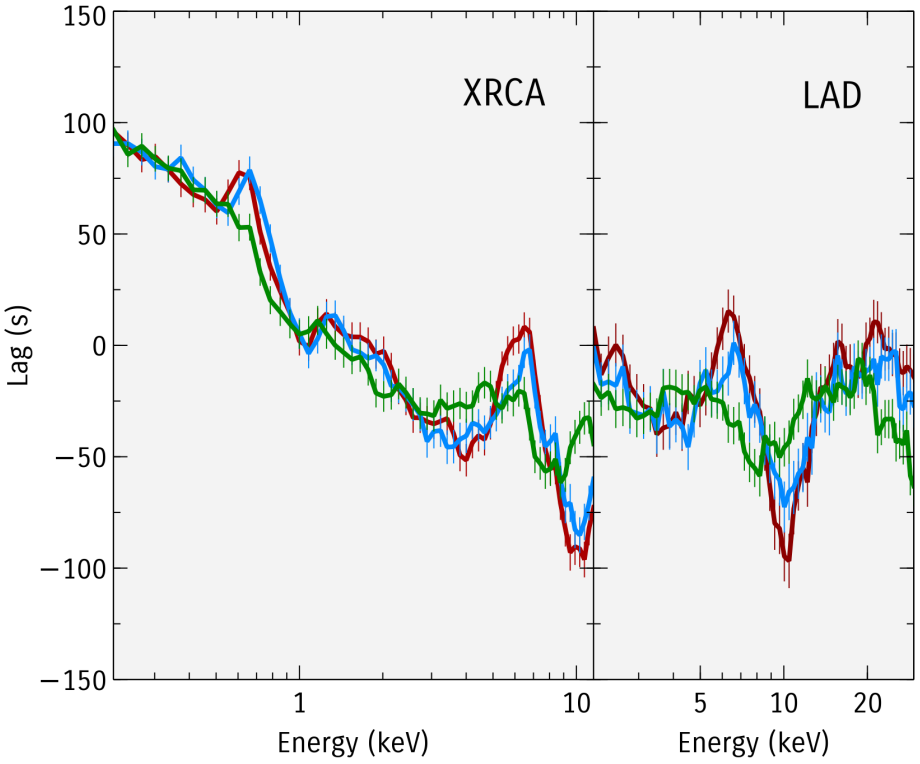

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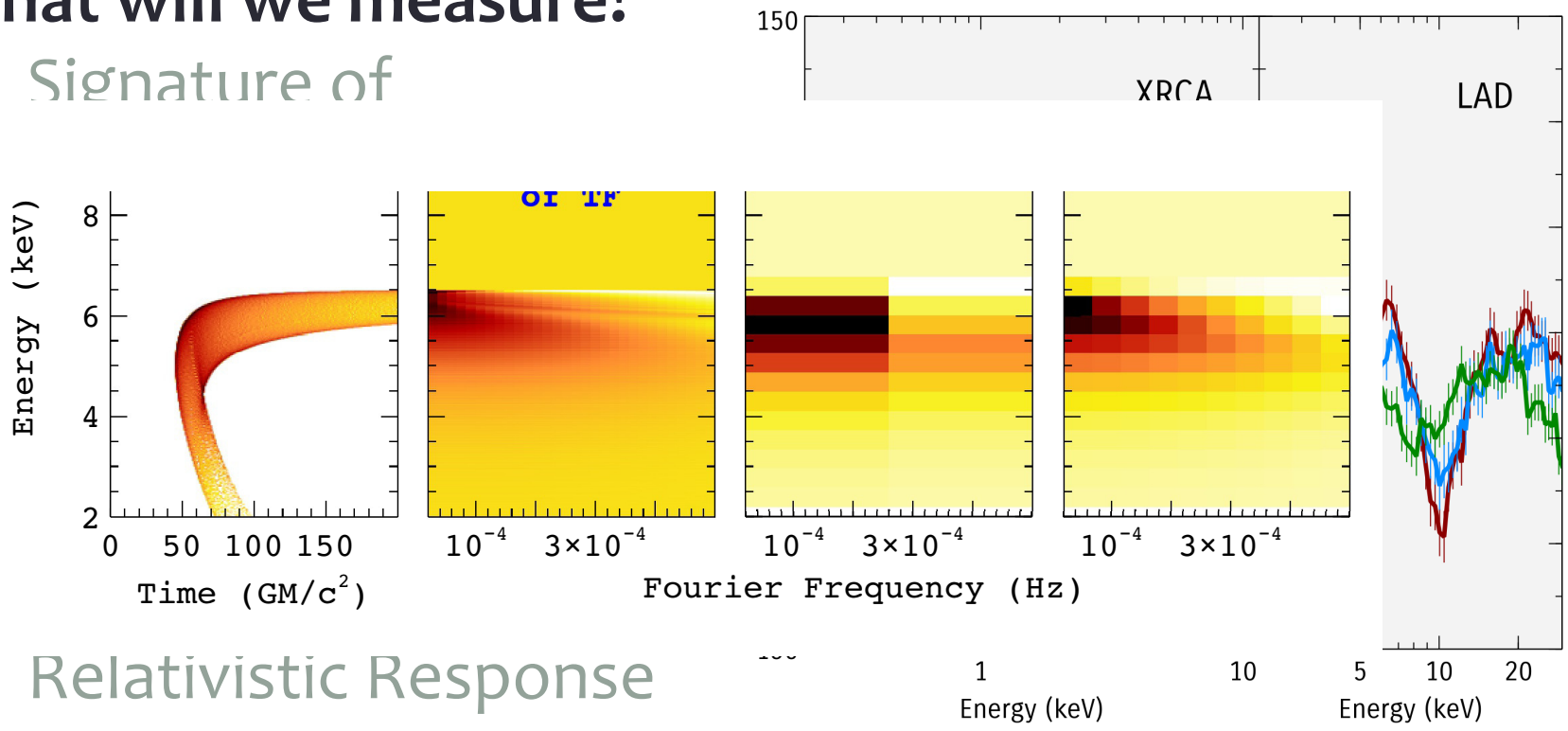

Summary

- Current measurements explores the tip of the iceberg of **relativistic reverberation in AGN.**

- **Orbital gaps**: we know how to handle them. Cons: missing some time-scale. Pros: gain long time-scales.

- With Strobe-X, tens of of sources will have **sub-Rg lag measurements**, opening new frontiers.

- Direct **measurement of Response function** of the iron line (& the whole spectrum) through frequency-resolved lag-energy → Geometry at horizon scales.

- Trade-off time: XRCA is downgrade is less sensitive to lag measurement than LAD.